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PATENT APPLICATION

BY

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FOR LETTERS PATENT FOR

AMPERAGE CONTROL FOR VALVES

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AMPERAGE CONTROL FOR VALVES

REFERENCE TO PROVISIONAL APPLICATION

[1]   Applicants claim priority based upon their provisional U.S. Patent Application Serial No. 60/412,508, filed September 20, 2002.

FIELD OF THE INVENTION

[2]   This invention relates to an amperage control for valves, and in particular for operating unipolar and bipolar rapid on-off valves adapted for use in a spray dampening system of a rotary printing press.

BACKGROUND OF THE INVENTION

[3]   Contemporary spray dampening control systems such as used in rotary printing presses utilize voltage as the source of electromagnetic energy to drive valves. For sake of simplicity, only a discussion of a unipolar valve is given. Bipolar counterpart valves have an additional stage which is conceptually identical, but opposite in polarity. For a description of unipolar versus bipolar operation, refer to our concurrently filed application entitled "Bistable Converter in a Spray Dampening System."

[4]   Referring to Figure 1, the most basic, and the most prevalent form of current technology consists of a load 10 comprising the solenoid coil of a valve, electrically connected in series with one or more transistors 12 acting as a switches. Opposing voltage potentials V_1, V_2 are applied to opposite ends of the circuit, 16, 18. Included in the schematic shown in Fig. 1 is parasitic impedance 14 introduced by connectors, long wire length, and other various electrical anomalies found in an actual application resulting in a voltage drop V_p. When the valve is to be engaged, the transistor switch 12 is closed, applying the voltage $[V_2-V_1-V_P]$ across load 10. V_1 is the ground voltage and V_2 is the positive voltage and V_P is the loss of voltage across impedance

14, which is inherent in all voltage control systems. The voltage across the load allows current to flow through the load according to Ohms Law, V=IR, where load 10 provides the resistance R. This current 12 generates a magnetic field, which actuates the valve. When the transistor switch 12 is opened, the flow of current stops, and the valve becomes de-energized.

[5]   Three types of voltage control systems have been offered in the prior art. They are conventional, step voltage, and pulse width modulated (PWM) voltage control techniques.

Conventional

[6]   The most widespread application is one where the solenoid device is activated by closing a switch. The solenoid device is deactivated by opening the switch, thus removing the voltage placed across the solenoid. In a unipolar solenoid valve, a mechanical device such as a spring returns the valve to its normal, de-energized state.

Step Voltage

[7]   A solenoid valve requires far more energy to open, than to remain open. There have been designs which deliver a higher "open" voltage to move the mechanical actuator to an "open" position (see Figure 3). This is followed by a less intense "hold" voltage to ensure that the actuator remains "open" for the desired interval.

Pulse Width Modulated (PWM) Voltage

[8]   For the same purpose as the "step voltage" system shown in Fig. 3, the PWM system uses full voltage for the "open" interval. Afterward the full voltage is switched on and off at intervals, to create a lower average voltage for the "hold" interval, as shown in Fig. 4.

SUMMARY OF THE INVENTION

[9]   The amperage or electrical current control technique of the present invention employs circuitry which senses the current flowing through the load 10 (Fig. 1). As such, it is

independent of applied voltage 16 so long as Ohms Law allows for the desired steady state current. The system can deliver any number of regulated current intervals of any magnitude, duration and polarity.

[10]   By directly manipulating the current in a solenoid valve control system rather than voltage, several benefits are realized. First, optimal accuracy and precision in the control of the valve is achieved. Magnetic force, like that used in solenoid valves, is generated by electrical current. A quick glance at any physics book reveals that, in the discussion of magnetism, the symbol for voltage ("V") is absent. Voltage is only indirectly involved in magnetism, in that it defines the maximum achievable current through a load according to Ohms Law. Direct, and regulated, control of electrical current results in the generation of magnetic fields which are more strictly controlled. Furthermore, many dynamic mechanical deficiencies reveal their presence by exerting an influence on the flow of current through the device. The amperage control system of the present invention self-adjusts, countering this type of induced and undesirable current activity. As a result, certain of these deficiencies are minimized or negated entirely. The outcome of using the current control system of the present invention is more predictable and more stable valve operation.

[11]   Second, the operation of current controlled valves becomes impervious to common electrical anomalies.

[12]   In actual application, a solenoid system is burdened by:

1.   Voltage fluctuation,

2.   Impedance variation due to conductor length or gauge,

3.   Impedance variation due to contacts at connection points,

4.   Impedance variation due to corrosion,

5.   Impedance variation due to component variation, and

6.   Impedance variation due to damage within the system

[13]   Since the drive stage senses the current delivered to the load in the present invention, the system can react to all of the adverse conditions outlined above. Only a catastrophic situation could impair the performance of a feedback regulated current control system.

[14]   Third, the current control system of the present invention provides electrically operated valves with optimal transitional performance. The fastest transitional response is achieved through two mechanisms:

1.   An over-current impulse, short in duration, can be delivered to the solenoid which far exceeds the maximum allowable steady-state power levels in both the load and the drive stage.

2.   The rate at which steady state current is reached through an inductive load (as in a solenoid valve) is expressed by the equation $I(t) = [1/L] \cdot \int v(t)\, dt$, where I is current, t is time, L is load, and V is voltage. As such, voltage determines the rate at which current increases through the coil in a valve. Therefore, the rate at which a magnetic field is generated by a solenoid is proportional to the applied voltage. The amperage control technique is able to exploit this fact to the fullest extent. Voltage in such a system is only limited by the absolute maximum rating of the electrical components. The electrical current is precisely regulated by the control system. Therefore, a voltage may be applied that would normally generate a steady-state current far greater than the safe limit of the components. This maximizes the rate at which a magnetic field is generated in the valve. However, the current in the presently disclosed

invention is limited to avoid exceeding maximum allowable power dissipation in the system.

[15]   Figure 5 is the step response of a voltage control system which applies voltage V across an inductive load at time t = 0. After time T, a steady state current I is achieved.

[16]   Figure 6 is the step response of a current control system which uses a much higher supply voltage. This system is designed to deliver current I across the same load as represented in Fig. 5. The current control system reaches steady state current much sooner, at which point the current is held constant.

BRIEF DESCRIPTION OF THE DRAWINGS

[17]   FIG. 1 is a schematic illustration of the voltage control circuit for a solenoid operated valve found in the prior art;

[18]   FIG. 2 is a time-voltage curve reflecting the prior art operation of the circuit of FIG. 1 in a conventional on-off manner;

[19]   FIG. 3 is a time-voltage curve reflecting the prior art step voltage operation of the circuit of FIG. 1;

[20]   FIG. 4 is a time-voltage curve reflecting the prior art pulse width modulated voltage (PWM) operation of the circuit of FIG. 1;

[21]   FIG. 5 is a time-current curve resulting from the application of a voltage V across an inductive load, showing that steady state current is ultimately achieved;

[22]   FIG. 6 is a time-current curve showing the step response of the current control system of the present invention;

[23]   FIG. 7 illustrates the current waveform over time of one cycle delivered through a

bipolar valve; and

[24]   FIG. 8 is a schematic diagram of a current control valve operation system,

including the current sensing stage of the present invention;

DESCRIPTION OF THE ILLUSTRATED EMBODIMENT OF THE INVENTION

[25]   Figure 7 displays the current waveform of one cycle of operation of the current

control system of the present invention delivered through a bipolar valve. Phase t1 is an impulse

current I1 delivered to set the valve actuator in motion. Phase t2 is a lower current I2 to stabilize

the valve in an open state. Phase t3 is an electrically idle interval. Phase t3 exists to conserve

energy, as well as to allow magnetic forces to dissipate prior to a following reverse condition.

Phase t4 is an oppositely polarized current impulse I3 to set the valve into motion toward a

closed state. The last phase applied is t5. Current level I4 stabilizes the valve in a closed state.

Schematic Diagram of Amperage Control Circuit

[26]   Figure 8 is a schematic diagram of the structure of the amperage control circuit of

the present invention as it pertains to one valve. Although there can be more valves, analysis of

one valve is sufficient for one skilled in the art to apply the teaching of the present invention to

multiple valves.

Process Control Stage

[27]   Referring to Figure 8, the process control stage 20 constitutes the intelligence of

the system, and can take the form of a PC, microprocessor, PLC, or as simple circuitry, which

establishes a sequence that determines when the valve should open and close. All operating and

control parameters (for example: valve open time, operating frequency, magnitude of current

intervals, duration of current intervals, polarity of current intervals, duration of idle intervals and

other operating parameters) are determined at and stored using the process control stage 20. The process control stage delivers instructions to the valve control stage 22, to determine when and how transitions at the valve 24 are to occur. In the illustrated embodiment of the invention, the process control stage 20 comprises microchip PIC18F242. However, other microchips may used. The process control stage 20 delivers operating data to the valve control stage 22 in the form of messages through a serial data interface.

Valve Control Stage

[28] The valve control stage 22 comprises one or more components that directly control the valve 24. All operating data is received from the process control stage 20, and transformed into electrical signals applied to the electrical operating mechanism of the valve 24. The valve control stage 22, by way of illustrative example, comprises four Allegro A3973 dual DMOS full-bridge microstepping PWM motor drivers. A description of the Allegro DMOS A3973 can be found in Allegro Microsystems, Inc. Data Sheet No. 29319.34, "Dual DMOS Full-Bridge Microstepping PWM Motor Driver," Dec. 1, 2000, published by Allegro Microsystems, Inc., Worcester, MA 01615-0036, which description is incorporated herein by reference. In the case of an "open valve" operation, the A3973 receives data from microchip PIC18F242 to apply an "open" current with a defined magnitude. At the output terminals of the A3973, full supply voltage is delivered to the coil of the operator of valve 24. Current in the coil of valve 24 is monitored by the current sensing stage 26. Information regarding the detected current is sent back to the valve control stage, described below. When the desired current is detected, the valve control stage 26 reduces the average applied voltage. In this state, the valve control stage makes adjustments to the voltage applied to the coil of valve 24 based on the current detection feedback,

maintaining a constant current output. The A3973 processor uses pulse width modulation to adjust the applied voltage to the operating coil of valve 24.

Current Sensing Stage

[29]   The current sensing stage 26 comprises one or more components that monitor the level of current flowing through the coil of the valve 24. In the presently described embodiment, this includes a small precision resistor in series with the coil of the valve 24. Current flowing through the valve operator coil also flows through this resistor, generating a small voltage drop. This voltage creates a feedback signal sent to the valve control stage 22, so that the valve control stage may make on-the-fly corrections to the current delivered to the operating coil of valve 24.

[30]   The data defining the valve operating parameters is transmitted to the valve driver A3973 (U2, Figure 1) that is incorporated in the valve control stage 22. The data is transmitted across two conductors in the form of serial messages. Driver A3973 decodes these messages and executes their contents with an on-board processor. The processor aboard driver A3973 activates a DMOS transistor bridge to apply current to the coil in valve 24. The DMOS transistor bridge is described in the above-identified Allegro Microsystems, Inc. Data Sheet No. 29319.34. Current which runs through the coil of valve 24 also runs through a sense resistor. This current generates a voltage that provides control feedback to A3973. Driver A3973, as part of valve control stage 22, uses this feedback to make adjustments to maintain the desired current through the coil of valve 24.

[31]   While the specific invention has been described with particular emphasis on illustrated embodiments, it will be obvious to those of ordinary skill in the art that variations in the illustrated embodiment of the present invention may be used and that it is intended that the invention may be practiced otherwise than as specifically described herein. Accordingly, this

invention includes all modifications encompassed within the spirit and scope of the invention as defined by the following claims.